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Chaotic biogeography-based optimization approach to target detection in UAV surveillance

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ABSTRACT

This paper describes a novel chaotic biogeography-based optimization (CBBO) algorithm for target detection by means of template matching to meet the request of unmanned aerial vehicle (UAV) surveillance. Template matching has been widely applied in movement tracking and other fields and makes excellent performances in visual navigation. Biogeography-based optimization (BBO) algorithm emerges as a new kind of optimization method on the basis of biogeography concept. The idea of migration and mutation strategy of species in BBO contributes to solving optimization problems. Our work adds chaotic searching strategy into BBO and applies CBBO in template matching. By utilizing chaotic strategy, the population ergodicity and global searching ability are improved, thus avoiding local optimal solutions during evolution. Applying the algorithm to resolving template matching problem overcomes the defects of common image matching. Series of experimental results demonstrate the feasibility and effectiveness of our modified approach over other algorithms in solving template matching problems. Our modified BBO algorithm performs better in terms of convergence property and robustness when compared with basic BBO.

1. Introduction

Unmanned aerial vehicles (UAV) are employed to execute dangerous or dull tasks for manned aircraft in both military and civilian realms [1–3]. It is of great necessity to provide UAV with precise target information for executing various missions, including navigation, autonomous landing and attack [4–6]. UAV are currently widely used in aerial surveillance, which acquires high accuracy of recognition. Global positioning systems (GPS) are installed on UAV navigation systems for target location generally. Advancements in digital camera technology have made significant performances in recent years with effective image processing software. Much attention has been directed forward vision-based methods for their usefulness in both commercial and military applications [7–11]. Vision strategy provides a better idea for safer and swifter UAV navigation [12]. A volume of works on visual control in formation flight and aerial refueling has been conducted by many researchers. It has been proposed to employ only natural features of scenes in computer vision systems during navigation [13]. Vision methods allow us to regulate the aircraft system in accordance with the surrounding variations. Therefore, it possesses great potential to adopt vision strategy for UAV navigation.

Multiple proposed vision methods attempt to implement UAV target detection through feature extraction. For instance, Hough Transform [14] is applied to edge extraction of targets and makes better performances in runway recognition. We apply template matching in this paper to solve the problem of target detection during surveillance. Common template matching algorithms generally require searching all the parts in the searching region. These methods call for tremendous calculation and end up with low efficiency. Multiple methods were proposed in succession aimed at accelerating matching velocity [15]. Feature-based approaches shrink the searching regions to enhance efficiency. Optimization-based matching involves various optimization algorithms such as the Gauss–Newton method [16], the Levenberg–Marquardt method and multiple swarm intelligence methods. Using the genetic algorithm (GA) as a substitution to common ergodic searching has been most frequently used for image matching [17]. However, when GA evolves to a certain extent, the accumulation of local optimization turns into the next generation through intersection and mutation. These properties of GA increase the difficulty of changing the fitness function values. In this case, the so-called "evolutionary stagnation" turns up. Swarm intelligence has absorbed the sights of

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many researchers in recent years. Bonabeau [18] defined the swarm intelligence as "any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insect colonies and other animal societies." BBO is an effective optimization method that was proposed by Simon in 2008 [19] for resolving engineering problems initially. It is a population-based searching algorithm on the basis of species' migration theory. The habitats (or islands) of species vary adaptively through information shared between candidate solutions. A typical feature of BBO is the modification of original population through migration concept. Another distinctive character is that BBO utilizes the fitness of each solution to determine the immigration and emigration rates. Good performances have been demonstrated by BBO on various single-objective benchmark functions [20–22]. It has also been applied to resolving problems including sensor selection power system optimization [23], groundwater detection [24], and satellite image classification [25].

Chaos exists widely in nature as a nonlinear phenomenon [26]. The chaos theory was established by Lorenz [27] to simulate the global weather system numerically. Lorenz found that subtle changes in initial conditions lead to radical difference among final results from the subsequent simulation and make long-term prediction impossible. We can observe such sensitive dependence on initialization not only in complex systems, but also in the simplest logistic equations. The chaotic system can travel all the states in accordance with the objective laws of the system itself without any repeat within a certain range. We adopt the chaotic searching strategy in this paper to modify the convergence velocity and accuracy of BBO. Furthermore, the proposed CBBO is employed to resolve the template matching problem during UAV surveillance.

The present paper introduces chaotic searching strategy into BBO for solving the problem of template matching. The remainder of this paper is organized as follows. Section 2 reviews the standard BBO and CBBO algorithm. Section 3 describes the structure of template matching approached by CBBO, while in Section 4, comparative experimental results are shown to elucidate the advantages of our proposed method. The final section contains our concluding remarks.

2. Chaotic biogeography-based optimization

2.1. Standard biogeography-based optimization

BBO is a very recently proposed intelligent optimization method that was inspired by the theory of biogeography. The biogeography-based model mainly concentrates on studying species distribution in adjacent habitats. Simon [19] related the phenomenon of migration and mutation during species with optimization problems in engineering and proposed BBO.

Each individual is called an island and represents a habitat that can be separated in BBO. Islands are regarded as points in searching space or solutions of optimization problems. Different species are distributed on islands, and their values of adaptability determine the scale of species. The habitat suitability index (HSI) is used to measure the adaptability of habitats. Features that are relevant with HSI, including rainfall, temperature, diversity of vegetation and square of lands, can be represented with suitability index variables (SIV). The relationship between HSI and SIV is shown as

$$\mathrm{HSI} = f(\mathrm{Habitat}) = f(\mathrm{SIV}_1 - \mathrm{SIV}_{\mathrm{near}}) \tag{1}$$

The crucial steps of BBO are migration and mutation of species. The immigration and emigration of species on islands enable habitats to share suitability. Random mutation among the species improves the suitability of habitats furthermore. BBO seeks out the optimal solutions in the searching space by mimicking the mechanisms above.

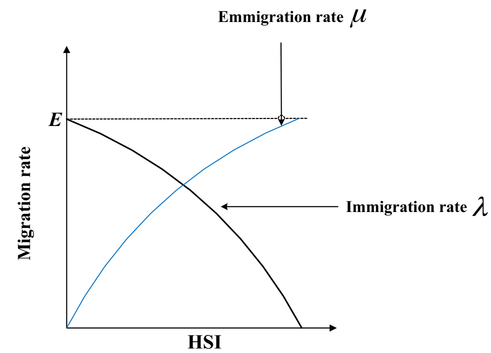

Fig. 1. Habitat migration rates vs. habitat suitability index.

2.1.1. Migration

The geography theory describes how species migrate among habitats. New species emerge and old ones vanish during the migration. Habitats with higher HSI own more species while low-HSI habitats contain fewer. Better solutions are similar to high-HSI habitats, and poor solutions represent low-HSI ones. Generally, the high-HSI habitats share higher emigration rates and lower immigration rates. High-HSI habitats draw on the verge of saturation and tend to resist immigrations. On the other hand, species on high-HSI habitats are more likely to emigrate to adjacent habitats and share their properties. Low-HSI habitats share relatively higher immigration rates and lower emigration rates accordingly. Immigration of new species improves the diversity of creatures and suitability of habitats.

The migration rates of islands are presented in Fig. 1. The emigration rate (μ) and immigration rate (λ) are functions of species population (S) on islands. Multiple functions can be employed to describe the relationship, and we adopt the cosine model in this paper, which is shown as

$$\lambda_k = \frac{1}{2}\left(\cos\left(\frac{k\pi}{n}\right) + 1\right) \tag{2}$$

$$\mu_k = \frac{E}{2}\left(-\cos\left(\frac{k\pi}{n}\right) + 1\right) \tag{3}$$

It is shown in Fig. 1 that the immigration rate and emigration rate change smoothly when species population on the island gets jolly large or small. And the rates vary fast under the circumstance that species population stays stable.

The maximum immigration and zero emigration emerge when no species exist in the habitat. The immigration rate decreases to zero while the emigration increases to the maximum value E as the number of species increases. The value of S is stabilized at one point when the two rates get equal.

Suppose that the species population of one habitat is S. λ_S and μ_S are the immigration rate and emigration rate respectively, which are defined as:

$$\lambda_S = I(1 - S/S_{\max}) \tag{4}$$

$$\mu_S = ES/S_{\max} \tag{5}$$

Suppose that $E = I$ for simplicity, so $\lambda_S + \mu_S = E$.

BBO makes decisions on whether to change SIVs according to the values of immigration rate and emigration rate. The specific procedure of migration is presented as follows:

Step 1: Calculate HSI of each island and sort them in the descending order;